DEFENCE **R&D** DÉFENSE

Stress Synergy in Proton Induced Single Event Effects in SRAM
The effects of prior gamma irradiation on the SEE cross sections for SRAM devices

L.S. Erhardt, T. Cousins and D. Estan

Defence R&D Canada
TECHNICAL REPORT
DREO TR 2001-122
November 2001

National Défense
Defence nationale

Canada

20020724 093

Stress Synergy in Proton Induced Single Event Effects in SRAM

The effects of prior gamma irradiation on the SEE cross sections for SRAM devices.

L.S. Erhardt, T. Cousins and D. Estan
Defence Research Establishment Ottawa

Defence Research Establishment Ottawa

AQ F02- 10-2469

Abstract

A study was conducted to determine the effect of prior exposure to radiation on the proton-induced single event effect (SEE) cross section for SRAM devices. This was done in order to determine whether or not proton testing of virgin parts accurately determines the likely rate of single event effects for these parts in a space environment. Two types of SRAM parts were exposed to various doses of gamma radiation and then tested with identical proton irradiations to determine their SEE cross sections. The results of these experiments were analyzed to determine the expected number of SEE events for these devices in typical space radiation environments, including the radiation environment of RADARSAT II. Both types of SRAM chips showed an increase in the SEE rate with prior radiation exposure. One type of SRAM, the D431000ACZ-70L, showed such a dramatic increase in the SEE rate that early failure in a satellite mission due to natural radiation, or in the event of an exo-atmospheric nuclear detonation, is likely.

Résumé

Une étude fut mise sur pied afin de déterminer les effets d'une pré-radioexposition sur la section efficace des perturbations isolées due à un champ de protons pour les mémoires SRAM. Le but de l'étude est de déterminer si un essai avec une pièce vierge dans un champ de protons donne un bon aperçu du débit des perturbations isolées qu'on retrouverait dans un milieu spatial. Deux types de mémoire SRAM furent exposées à de différentes doses de rayonnement gamma pour par la suite étudier leurs sections efficaces de perturbations isolées dans à un champ de protons. Les résultats furent analysés afin de déterminer le débit de perturbations isolées qu'on s'attendrait à observer dans un milieu spatial, incluant l'environnement de RADARSAT II. Les deux types de mémoire ont démontrées des débits de perturbations isolées élevés avec une pré-radioexposition. Une des mémoires SRAM, le D431000ACZ-70L, a démontrée une augmentation tellement grave dans le débit de perturbations isolées, qu'une défaillance précoce durant la mission d'une satellite due au rayonnement de fond, ou a une explosion nucléaire exo-atmosphérique, serait probable.

This page intentionally left blank.

Executive summary

Introduction: At the inaugural meeting of NATO Nuclear Protection Sub-Group (NPSG) ad-hoc committee on writing Allied Engineering Publication 50 (AEP-50) "Space Radiation Hardening Guidelines for Military Satellites: Electronics and Photonics", it was suggested that there existed a potentially fatal flaw in the current methodology for qualifying electronic components for space. Namely, current methodology rests almost completely on test results from unirradiated, or "virgin" parts in the myriad of fields necessary for qualification. The real-life situation does, of course, not mirror this as the satellite is subjected to a variety of radiation fields at variable rates over its mission lifetime. In light of this, a study was conducted to determine the effect of prior exposure to radiation on the proton-induced single event effect (SEE) cross section for SRAM devices.

Results: Two different SRAM devices were tested for proton-induced SEE, after being exposed to gamma radiation. The first devices tested were MT5C2568 SRAM chips. These devices showed an increase in the single event upset (SEU) cross section that would lead to a 50 % and 70 % increase in the number of expected upsets for chips exposed to a total ionizing dose (TID) of 50 kRad(Si) and 100 kRad(Si) respectively. The second set of chips that tested was comprised of D431000ACZ-70L SRAM. These devices showed a large increase in the SEU cross section with TID, and in addition they exhibited a large number of latch-up events. The increase in the expected number of upsets was determined to be approximately 30, 100 and 300 times greater for parts exposed to 25, 50 and 100 kRad(Si) TID respectively than for virgin parts.

Significance and Future Plans: The impact of prior irradiation on the D431000ACZ-70L SRAM chips was of such a high level that it could have significant impact on a satellite mission. If these devices were to be deployed in a mission with radiation environment similar to RADARSAT II, the upset and latch-up rate would increase to unacceptable levels by the end of a 5.25 year mission. In the event of an exo-atmospheric nuclear detonation, the radiation exposure would be enough to cause a significant portion of the SRAM device to latch-up. These results could have significant impact on the way in which space qualification of electronic devices is done. The testing of virgin parts for single event effects can significantly under-estimate the rate of these events in an actual space environment. In light of the concerns of the NATO NPSG in this area [2], there should be a re-evaluation of the fundamental assumptions and current practices in qualifying components for space applications.

Sommaire

Introduction: À la séance d'ouverture de *NATO Nuclear Protection Sub-Group (NPSG) ad-hoc committee on writing Allied Engineering Publication 50 (AEP-50) "Space Radiation Hardening Guidelines for Military Satellites: Electronics and Photonics"*, il fut suggéré qu'il existe un problème avec la méthodologie courante gouvernant l'admissibilité des pièces électroniques pour le milieu spatial. Spécifiquement, la méthodologie courante dépend presque entièrement sur des essais avec des pièces vierges dans une variété de champs de rayonnement. En réalité, ces essais ne reflètent pas la durée de vie d'une mission pour un satellite dans le milieu spatial, où il y a une variété de champs de rayonnement a une variété de débits de dose. Une étude fut donc effectuée afin de déterminer les effets d'une pré-radioexposition sur la section efficace des perturbations isolées due à un champ de protons pour les mémoires SRAM.

Résultats: Deux types de mémoire SRAM furent exposées à de différentes doses de rayonnement gamma pour par la suite étudier leurs sections efficaces de perturbations isolées dans à un champ de protons. Les premières pièces évaluées furent les SRAMs MT5C2568. Ceux-ci ont démontrées une augmentation dans la section efficace des perturbations isolées qui résulterait en une augmentation de 50 % et 70 % dans le nombres de perturbations isolées pour des pièces exposées à des doses de rayonnement gamma à 50 kRad(Si) et 100 kRad(Si) respectivement. Le deuxième type de pièce évaluée fut le SRAM D431000ACZ-70L. Avec une pré-radioexposition, ceux-ci ont démontrées une grande augmentation dans la section efficace des perturbations isolées, ainsi qu'un grand nombre de cas de verrouillage. L'augmentation dans le nombre de perturbations isolées fut déterminée à être approximativement 30, 100 et 300 fois plus élevé qu'une pièce vierge pour les pièces exposées à des doses de rayonnement gamma à 25, 50 et 100 kRad(Si) respectivement.

Importance: L'effet d'une pré-radioexposition chez le SRAM D431000ACZ-70L fut de telle importance que ceci pourrait avoir un impact néfaste sur la mission d'un satellite. Si ces pièces sont utilisées dans un milieu spatial semblable a celui de RADARSAT II, le nombre de perturbations isolées ainsi que le nombre de cas de verrouillage approcherait un niveau inacceptable à la fin de 5.25 années. Dans le cas d'une explosion nucléaire exo-atmosphérique, la radioexposition serait suffisante pour causer des défaillances dans une grande portion de la pièce en question. Ces résultats pourraient jouer un rôle important en établissant la méthodologie gouvernant l'admissibilité des pièces électroniques pour le milieu spatial. L'évaluation de pièces de mémoire SRAM vierges en ce qui concerne le débit de perturbations isolées peut grandement sous-estimer le rendement de perturbations isolées dans un milieu spatial réel. À cause des concernes d'OTAN dans cette zone, il devrait être une réévaluation des croyances fondamentales et des pratiques en vigeur pour qualifier des pièces de mémoire pour des applications en espace.

Erhardt, L.S.; Cousins T. and Estan, D. 2001. Les effets de la pré-radioexposition chez le débit de perturbations isolées dans les pièces de mémoires SRAM. DREO TR 2001-122. Defence Research Establishment Ottawa.

Table of contents

List of figures

List of tables

1. Introduction

At the inaugural meeting of NATO Nuclear Protection Sub-Group (NPSG) ad-hoc committee on writing Allied Engineering Publication 50 (AEP-50) "Space Radiation Hardening Guidelines for Military Satellites: Electronics and Photonics", it was suggested that there existed a potentially fatal flaw in the current methodology for qualifying electronic components for space. Namely, current methodology rests almost completely on test results from unirradiated, or "virgin" parts in the myriad of fields necessary for qualification. The real-life situation does, of course, not mirror this as the satellite is subjected to a variety of radiation fields at variable rates over its mission lifetime. It is necessary to address the question of whether or not a symbiotic relationship exists between two or more components of this radiation environment: *does this variegated radiation environment produce effects that exceed the sum of individual tests at individual facilities.* The term 'stress synergy' was coined to describe these possible effects [1]. Stress synergy can take many forms, some of which are delineated below (and approved by NPSG for study [2]):

a) Nuclear Weapon (NW) irradiation of a satellite well into its mission

b) Natural Irradiation of a satellite following NW exposure.

c) Combination of diverse natural environments.

All various combinations of the above are being examined – in particular White Sands Missile Range (WSMR) and Defence Research Establishment Ottawa (DREO) are examining a) and b) [3]. However one aspect of the third stress-synergistic mechanism produced extremely interesting and germane results reported on here. This involved proven synergy between high-energy proton Single Event Effects (SEE) and Total Ionizing Dose (TID). (It should be noted that this effect might not be limited to natural environments, since NW can clearly provide a large TID.)

2. Theory

2.1 Single Event Upsets

Proton-induced single event effects (SEEs) in digital electronics are of great importance for space applications. SEEs may take the form of Single Event Upset (SEU), Single Event Latchup (SEL), Single Event Burnout (SEB) or Single Event Gate Rupture (SEGR). Results can range from trivial and recoverable to catastrophic – complete mission failure [4, 5]. For this work, we concentrate on SEUs in proton-rich environments, which have been shown to be the most probable in recent space-cased experiments. The SEU cross section as a function of energy for protons- is generally zero up to a threshold energy, above which it increases to an asymptotic value (see Figure 4 and Figure 7 for examples of this behaviour). This behaviour can be described quite well by the empirical Bendel function [6]. The original form of the Bendel function used only one free parameter, but data are generally better fit with the Bendel 2-parameter function [7]:

$$\sigma(E) = \left(\frac{B}{A}\right)^{14} \left[1 - \exp\left(-0.18y^{1/2}\right)\right]^4$$

where:

$$y(E) = (E - A)\left(\frac{18}{A}\right)^{1/2} \qquad \text{for } E > A$$

$$y(E) = 0 \qquad\qquad\qquad \text{otherwise}$$

and where E is the proton energy in MeV, F(E) is the cross section in units of 10^{-12} cm^2/bit and A and B are the fit parameters. An alternate formulation of the Bendel 2-parameter fit uses parameters that are more physically meaningful [8]:

$$\sigma(E) = S \left[1 - \exp\left(-0.18y^{1/2}\right)\right]^4$$

where y is defined as above, the S parameter is the asymptotic cross section and the A parameter is the threshold energy. This form of the Bendel function will be used here, due to its more intuitive form.

2.2 Mission Impact

The expected proton energy spectrum must be considered in order to determine the impact that changes in the SEU cross section will have on SRAM performance in a space environment. A typical satellite in earth orbit is exposed to protons that have an energy spectrum that is, to a good approximation, inversely proportional to energy. The proton energy spectrum can be written as [6]:

$$N(E) = N_o \left(\frac{1}{E} \right)$$

where N_o is the normalization factor. The number of expected SEU events is given by the convolution of the proton energy spectrum with the cross section. The number of expected SEU events for an SRAM chip in a given space environment can therefore be written as:

$$U(E_{max}) = \int_0^{E_{max}} \sigma(E) N(E) dE$$

where E_{max} is the cut-off energy for the integral (the maximum proton energy considered).

It is the norm to try to assess mission impact from the radiation environment by predicting the number of SEUs in any particular orbit via irradiation of a virgin part. This study examines the validity of this methodology by comparing the number of SEUs predicted for previously irradiated parts in addition to virgin parts. It will be shown that the synergistic effects between high-energy proton SEE and gamma ray TID have significant effects on the predicted number of SEUs.

3.   Experimental Procedures

Two different types of SRAM chips were tested in a series of experiments at the TRI-University Meson Facility (TRIUMF) in Vancouver, British Columbia and at Defence Research Establishment Ottawa (DREO) in Ottawa, Ontario. The initial gamma irradiation of the SRAM chips was performed at DREO using the GB150-C gamma source. Proton irradiations were all preformed at the TRIUMF Proton Irradiation Facility (PIF).

3.1   Facilities

3.1.1   DREO's GB150-C

The GB-150C is a stationary 5000 Ci ^{60}Co source that is held in a lead container within a shielded 3 m $\times$ 4 m room at DREO (see Figure 1). When activated, the source is raised up to a height of approximately 1.3 metres, where an aperture in the lead container allows it to shine into the room. The dose rate of the irradiation is determined by the distance from the source aperture. A track-mounted moveable platform allows for reproducible positioning (and therefore dose rate) of the samples. The maximum usable dose rate with the GB150-C is approximately 60 kRad/h (Si). This dose rate is achieved by mounting samples on an acrylic plate attached to the mouth of the aperture. The irradiations for this study were all performed at the maximum dose rate.
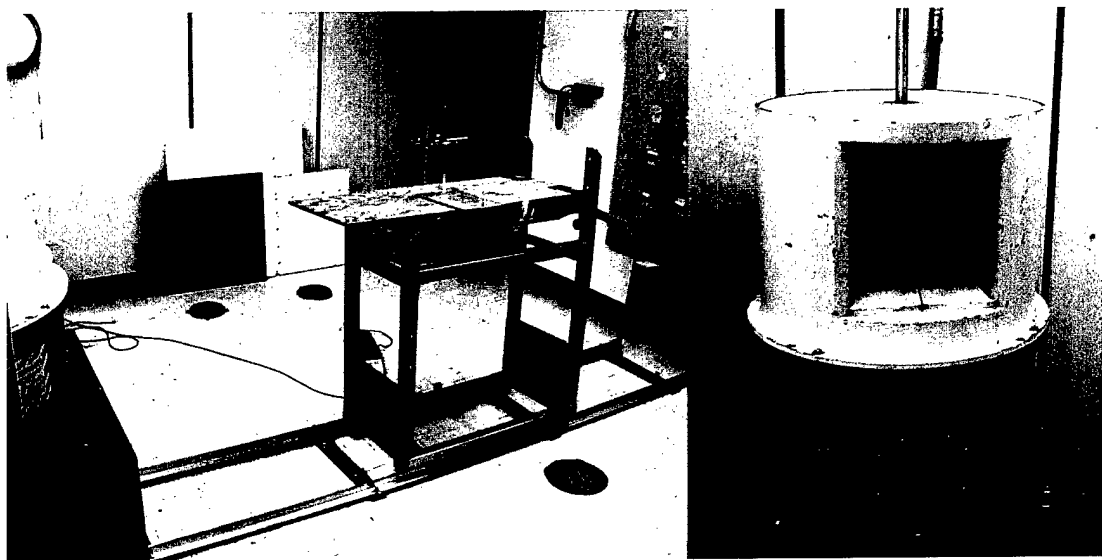
Figure 1. The GB150-C gamma ray source at DREO. The GB-150C is a 5000 Ci ^{60}Co source. The picture on the right shows the lead source container with the source aperture in the centre. The picture on the left shows the source room with the track-mounted movable platform for sample positioning.

3.1.2 TRIUMF PIF

TRIUMF is a multi-user cyclotron facility located in Vancouver, British Columbia. The unique feature of the TRIUMF cyclotron is that it is capable of simultaneously extracting several proton beams of different energies and intensities. The TRIUMF PIF makes use of two beam lines (1B and 2C) from the TRIUMF cyclotron. The facility was adapted, with the help of DREO, for low intensity radiation damage studies of electronics, detector components and other materials. The facility is also used for cancer treatment, specifically for proton irradiation of ocular melanoma. The TRIUMF PIF is shown in Figure 2. Beamline 2C provides protons of energy between 65 and 120 MeV, with energies as low as 12 MeV possible by beam degradation. Beamline 1B provides protons energies from 180 to 500 MeV with degraders providing energies as low as 120 MeV.
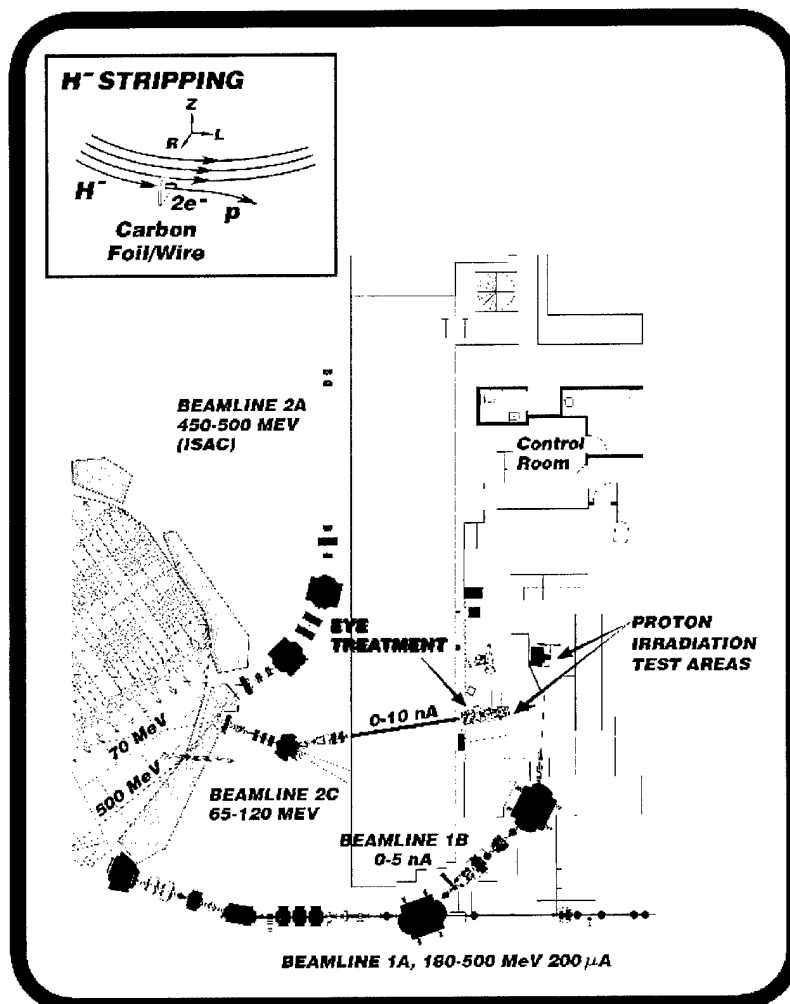
Figure 2. The TRIUMF Proton Irradiation Facility. Beamlines 1B and 2C provide protons with energies ranging from 12 MeV to 500 MeV to two locations in the test area. Figure provided courtest of Dr. E. Blackmore, director of the TRIUMF PIF.

3.2 Tested Parts and Initial Irradiation Conditions

3.2.1 MT5C2568 SRAM Chips

The MT5C2568 is a 32k × 8 SRAM chip produced by Micron Semiconductor Products. Nine of these chips were tested in total. The chips were divided into three groups of three. Each group was given a different TID from the GB-150C source at DREO, at a dose rate of approximately 60 kRad(Si)/hour (see section 3.1.1). The groups were exposed to 0, 50 and 100 kRad(Si).

Table 1. Initial irradiation conditions for the MT5C2568 SRAM chips. Each group consisted of three chips that were irradiated identically. Irradiations were performed in the GB-150C gamma-ray source at DREO (see section 3.1.1).

Group	Dose kRad(Si)	Dose Rate kRad(Si)/hour
M1	0	0
M2	50	60
M3	100	60

3.2.2 D431000ACZ-70L SRAM chips

The D431000ACZ-70L is a 128k x 8 SRAM chip produced by NEC. These experiments were performed in December 2000, using sixteen of the D431000ACZ-70L chips, divided into four groups. The groups were exposed to doses 0, 25, 50 and 100 kRad(Si) from the GB-150C source at DREO, at a dose rate of 60 kRad(Si)/hour (see section 3.1.1).

Table 2. Initial irradiation conditions for the D431000ACZ-70L SRAM chips. Each group consisted of four chips that were irradiated identically. Irradiations were performed in the GB-150C gamma-ray source at DREO (see section 3.1.1).

Group	Dose kRad(Si)	Dose Rate kRad(Si)/hour
D1	0	0
D2	25	60
D3	50	60
D4	100	60

3.3 SEE Test Equipment and Procedures

Tests for proton-induced single event effects were carried using the JD Instruments ATV Digital Tester (see section 3.3.1). The tests consisted of loading a pattern of all ones (or all zeros) into the SRAM chip, irradiating the chip with protons, and then reading out the chip's memory state. The number of bits that changed state during the irradiation was recorded and used to calculate the upset cross section. Each chip was irradiated with a variety of proton energies and tested multiple times in both initial memory states in order to improve the precision of the cross section measurement. A remotely controlled x-y stage was used to move the test chips into and out of the proton beam without having to physically access the test area.

3.3.1 JD Instruments ATV Digital Tester

The Algorithmic/Test Vector (ATV) is a portable digital tester produced by JD Instruments[1]. The ATV is shown in Figure 3. With the current test board and daughter board configuration, the ATV allows the user to test up to four memory devices in sequence and allocates up to 24 output ports for addressing and/or control signals as well as 8 input/output ports for data lines. The ATV is controlled by a proprietary piece of software called DTE (Dynamic Test Environment). Within DTE, a project is designed in order to test any given part. The project development is broken down into three steps: the timing diagram, the part description and pin-out and the test program. The test programs are completely user defined and written in software. Read/write loops can be incorporated into the code for diagnostic purposes.
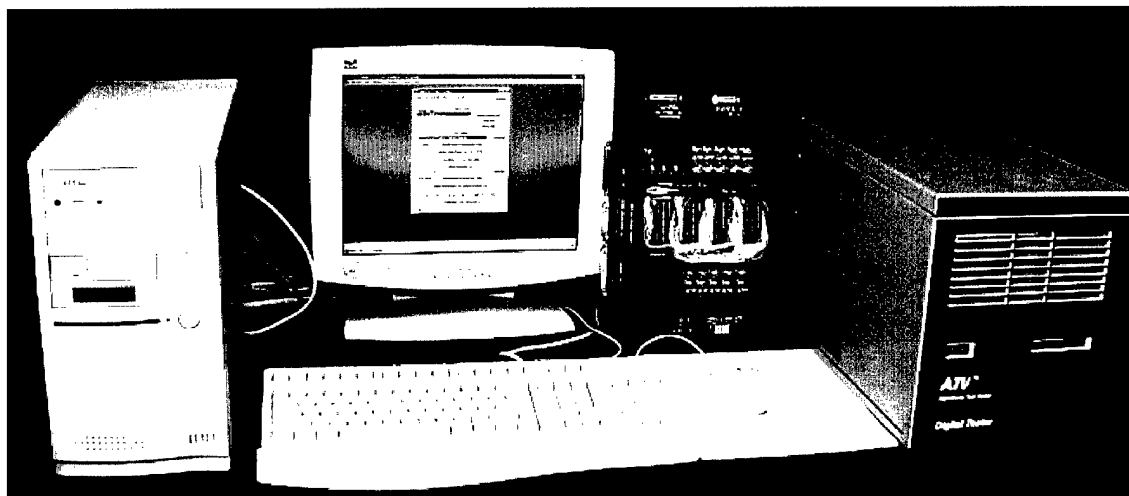
Figure 3. The JD Instruments Algorithmic/Test Vector (ATV). All proton-induced single event effect tests of SRAM were performed using this equipment.

---

[1] JD Instruments, PO Box 31154 Albuquerque, NM. Internet: http://www.jdinstruments.net/

3.3.2 MT5C2568 SRAM Chips

These chips were tested at the TRIUMF PIF in August 2000. All of the chips were exposed to identical proton fluences at energies of 13.5, 20.0, 35.4, 57.7, 101.5, 194, 348 and 490 MeV. Each chip was tested three times in both memory states (all 0s or all 1s). The irradiations were all done in order of increasing energy, with the exception of the 101.5 MeV irradiations, which were the first to be performed. The measurements at 101.5 MeV were not included with these data due to anomalies with the measurements. A summary of the irradiations that were performed is shown in Table 3.

Table 3. Summary of the proton irradiations performed on the Mt5C2568 SRAM chips. All groups of chips were exposed to identical irradiations. There were six irradiations per chip per energy, three with each memory state (all 0s or all 1s). The higher energy irradiations were done to a lower fluence due to time constraints. The chips were also irradiated at 101.5 MeV, but these data were not included due to anomalies with the measurements.

Energy (MeV)	Proton Fluence (p/cm^2)	Number of Trials	
		0s	1s
13.5	2.85×10^9	3	3
20.0	2.85×10^9	3	3
35.4	2.85×10^9	3	3
57.7	2.85×10^9	3	3
194	8.2×10^8	3	3
348	8.3×10^8	3	3
490	7.6×10^8	3	3

3.3.3 D431000ACZ-70L SRAM chips

These chips were tested at the TRIUMF PIF in December 2000. The chips were exposed to identical fluences at energies of 13.5, 20.0, 35.4, 57.7, 101.5, 194, 348 and 489 MeV. Each chip was tested three times in both memory states (all 0s or all 1s). The irradiations were all done in order of increasing energy. A summary of the irradiations that were performed is shown in Table 4. Not all of the chips were exposed to the entire range of proton energies. Groups D3 (50 kRad) and D4 (100 kRad) had so many errors at the higher energies that the exact number could not be determined accurately.

Table 4. *Summary of the proton irradiations performed on the D431000ACZ-70L SRAM chips. The higher energy irradiations were done at a lower fluence due to time constraints. Groups D3 (50 kRad) and D4 (100 kRad) were not exposed to the all of the proton energies due to the huge number of errors produced at the lower energies.*

Energy (MeV)	Proton Fluence (p/cm^2)	Groups Irradiated	Number of Trials	
			0s	1s
13.5	2.3×10^9	D1 – D4	3	3
20.0	3.2×10^9	D1 – D4	3	3
35.4	4.9×10^9	D1 – D4	3	3
57.7	7.1×10^9	D1 – D4	3	3
101.5	1.1×10^{10}	D1 – D3	3	3
194	6.8×10^9	D1 – D3	3	3
348	9.3×10^9	D1, D2	3	3
490	1.4×10^9	D1, D2	3	3

The large number of errors that were encountered, especially in groups D3 and D4, presented an unexpected difficulty during the performance of the proton-induced SEE measurements. The software that was used along with the ATV test equipment was designed to report both the total number of bits in the SRAM that changed state and the number of SRAM addresses (groupings of 8 bits) that encountered errors. The difficulty that was encountered was that the bit-error counter saturated at 4096 errors. Above this number of bit errors, the only information that was available was the number of address errors.

This becomes a problem when the number of memory addresses that report errors approaches the total number of addresses in the SRAM chip. When this occurs, the probability of there being multiple bit errors at a single address increases greatly. In order to correct for this, a statistical approach was used to estimate the probable number of bit errors given the number of address errors that occurred. This statistical approach is outlined in Appendix A. Uncertainties in this correction limit the range of address errors over which this correction is effective. For this reason, groups D3 and D4 were not exposed to all proton energies. This software problem has since been resolved, and will not be an issue for future experiments.

4. Results

An increase in the cross section for single event upsets was seen in both the MT5C2568 SRAM chips and in the D431000ACZ-70L chips, however the effect was much more pronounced in the latter.

4.1 MT5C2568 SRAM Chips

The single event upset (SEU) data for the MT5C2568 chips are summarized in Figure 4. These data are averaged values for all of the chips and includes data from both (all 0s and all 1s) memory states. Figure 4 also shows curves fit using the Bendel 2-parameter fit (see section 2.1). There is a small, but statistically significant, increase in the upset cross section for the chips that were irradiated with gamma rays prior to proton exposure.

Figure 4. Averaged SEU cross sections for the MT5C2568 SRAM chips. The error bars represent the standard deviation of all of the measurements and the curves are Bendel 2-parameter fits to the data. The fit parameters are tabulated in Appendix B. These data are for prior gamma exposures of 0, 50 and 100 kRad. There is an increase in the upset cross section with prior irradiation.

The important effect for the operation of an SRAM chip in a space environment is the number of likely upsets for the duration of the mission. This was discussed in section 2.2. The expected number of upsets is a convolution of the upset cross section with the energy spectrum. Figure 5 shows a plot of the number of expected upsets for the MT5C2568 SRAM chip that was tested. The calculations of the number of upsets were done using a $1/E$ energy spectrum convolved with the fitted Bendel 2-parameter curves from Figure 4. The plots in Figure 5 are shown as a function of the cut-off energy for the integral (see section 2.2). The plots in Figure 5 are meant for comparison with each other, and not as a prediction of the number of upsets for a particular orbit. To make such a prediction, the details of the proton environment for a specific orbit would have to be used for the convolution.
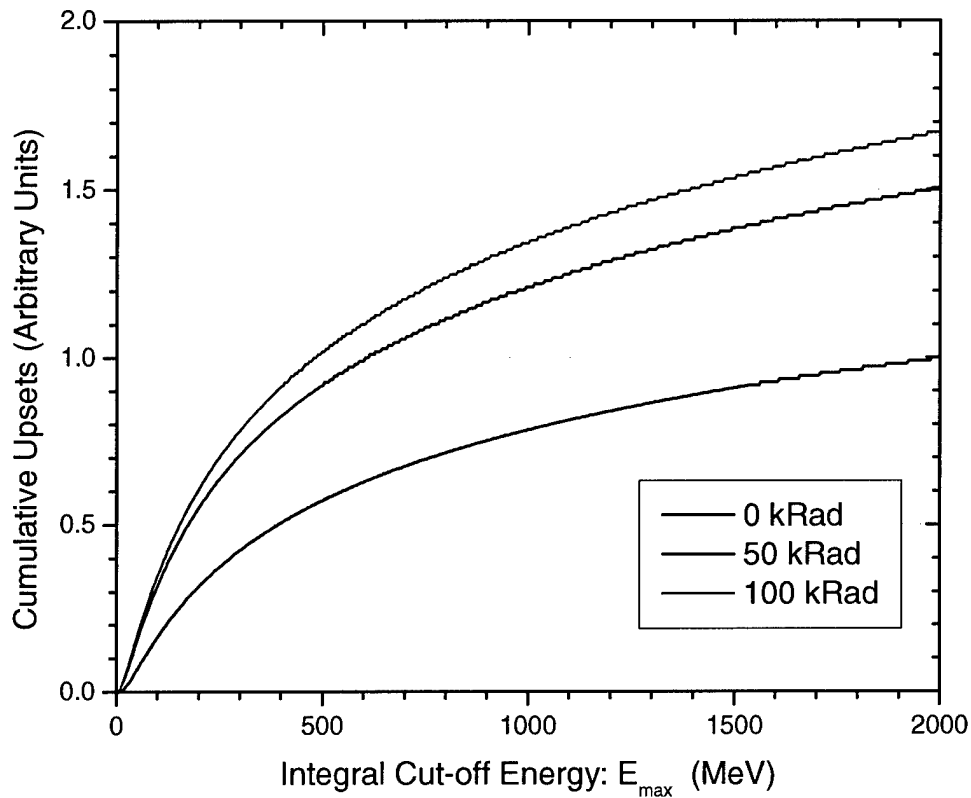
Figure 5. Cumulative upsets for the MT5C2568 SRAM chips in a proton environment with energy spectrum as outlined in section 2.2. The cumulative upsets are shown, in arbitrary units, as a function of cut-off energy for the integral. The results have been normalized to make upsets for the virgin parts (0 kRad) to be 1 at 2 GeV to allow for easy comparison between groups.
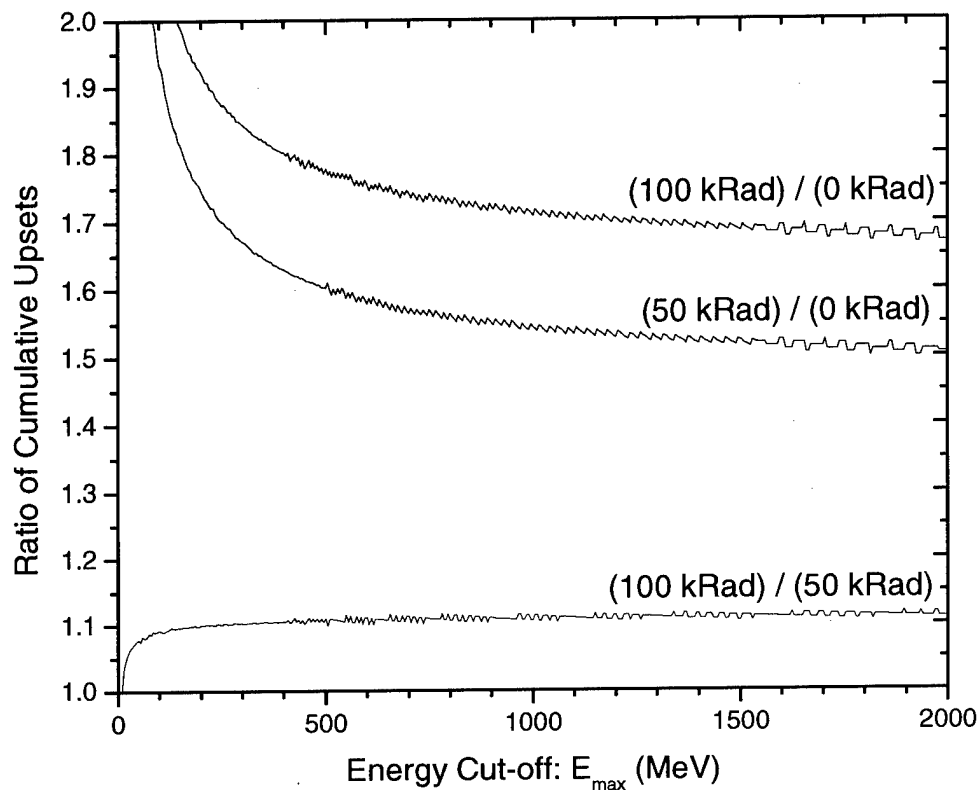
Figure 6. *The ratio of cumulative upsets as a function of integral cut-off energy for the three different irradiation conditions of the MT5C2568 SRAM chips. The chips irradiated to 50 kRad(Si) are expected to show 50 to 60 % more upsets and the chips irradiated to 100 kRad(Si) are expected to show 70 to 80 % more upsets than the virgin chips in a space (proton-rich) environment.*

For a more meaningful comparison, a plot of the ratio of the number of expected upsets as a function of the integral cut-off energy is shown in Figure 6. This plot clearly shows the increase in the number of expected upsets with prior irradiation. The group of chips that was irradiated with 50 kRad(Si) before proton irradiation shows at least a 50 % increase (over virgin parts) in the number of expected upsets due to proton interactions. The group exposed to 100 kRad(Si) shows an increase in the expected upset rate of at least 70 %. This increase is even higher if the integral cut-off energy is lower than 2 GeV. If one assumes an energy cut-off somewhere between 500 MeV and 2 GeV for the porton spectrum, the increase in the expected upset rate is between 50 and 60 % for the chips in group M2 (50 kRad(Si)) and between 70 and 80 % for the chips in group M3 (100 kRad(Si)).

4.2 D431000ACZ-70L SRAM chips

The single event upset (SEU) data for the D431000ACZ-70L chips are summarized in Figure 7. These data are averaged values for all of the chips and includes data from both (all 0s and all 1s) memory states. Figure 7 also shows curves fit using the Bendel 2-parameter fit (see section 2.1). There is a large increase in the upset cross section for the D431000ACZ-70L chips that were irradiated with gamma rays prior to proton exposure.

The effect for the D431000ACZ-70L chips is much more pronounced than for the MT5C2568 chips. For the D431000ACZ-70L chips the increase in the asymptotic cross section for the chips exposed to 100 kRad(Si) (relative to the virgin parts) is over two orders of magnitude, whereas the MT5C2568 chips showed an increase of less than a factor of 2 for similar conditions.

Figure 7 shows a cross section calculated using the number of bits that changed state during proton irradiation. This was, however, not the only effect that was noted during
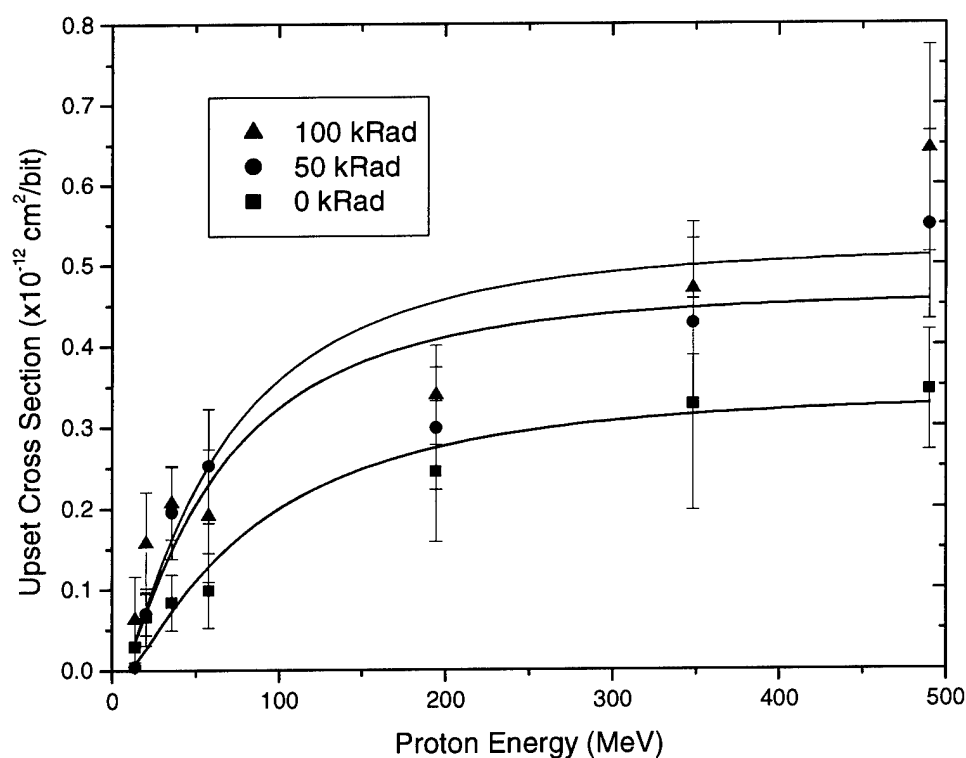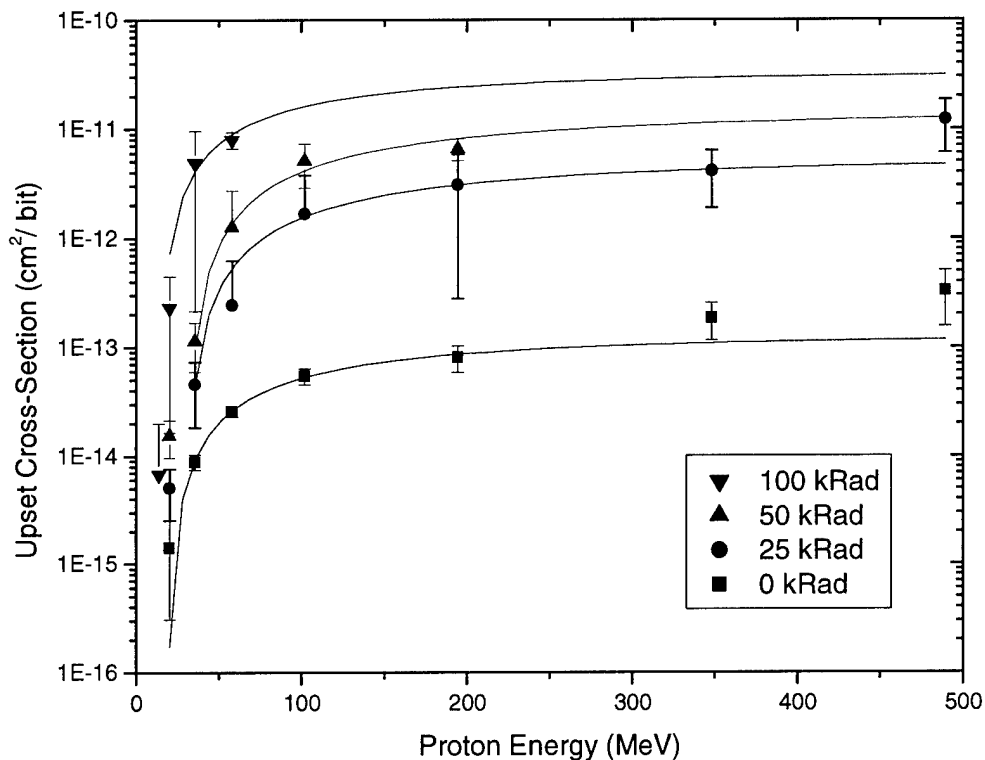

Figure 7. *Averaged SEU cross sections for the D431000ACZ-70L SRAM chips. The error bars represent the standard deviation of all of the measurements. The solid lines are Bendel 2-parameter fits to the data. The fit parameters are tabulated in Appendix B. There is a large increase in the upset cross section with prior irradiation.*

the proton irradiations. There was also permanent damage done to the D431000ACZ-70L chips during the proton irradiations. In addition to the bit upsets, a number of latch-up events also occurred (see Figure 8). These events involve bits becoming stuck in one state. These were detected as errors that were reported when reading out the memory state of the SRAM chip immediately after writing to it, before the proton irradiation. Each measurement consisted of a number of steps:

1. A memory pattern (all 1s or all 0s) was written to the chip.

2. The memory pattern was immediately read-out and the number of reported errors was noted.

3. The chip was irradiated with protons.

4. The memory pattern was read-out again and the number of errors was noted.
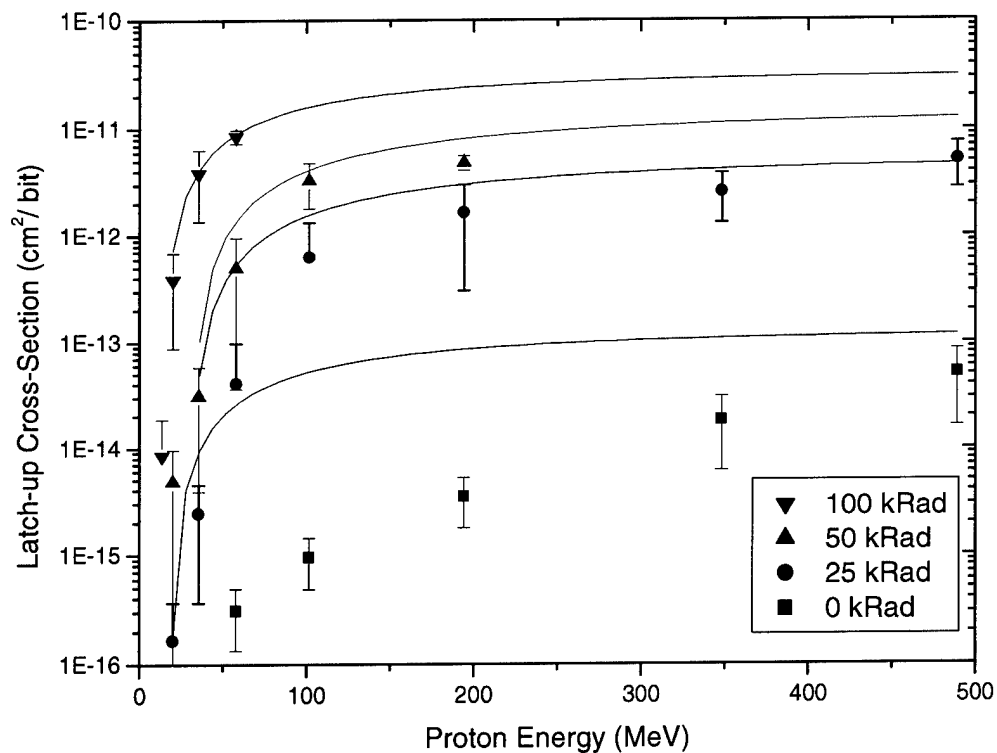
Figure 8. Averaged latch-up cross sections for the D431000ACZ-70L SRAM chips. The error bars represent the standard deviation of all of the measurements. The curves shown are the Bendel 2-parameter fits to the upset cross section data shown in Figure 7. There is a marked difference between the upset and latch-up cross section for the virgin chips, but little difference for the chips that were previously irradiated.

The upset cross section was calculated using the difference in the number of errors reported in steps 2 and 4. The latch-up cross section was calculated using the difference in the number of errors reported in step 2 from one measurement to the next. The measured latch-up cross sections for the D431000ACZ-70L chips are shown in Figure 8. Figure 8 also shows the Bendel 2-parameter fits to the upset cross section data shown in Figure 7. This is included to allow for a comparison between the two cross sections. It can be seen that the upset and latch-up cross sections are nearly identical for the chips that were previously irradiated, but the latch-up cross section for the virgin chips is much smaller than the upset cross section.

The relative increase in the latch-up cross section with increasing prior TID exposure can be seen more easily in Figure 9. Figure 9 shows the ratio between the measured latch-up and upset cross sections as a function of energy for the D431000ACZ-70L chips that were tested. There is a clear trend in these data showing that the number of latch-up events (relative to SEU) increases with prior exposure to gamma radiation.

The difference between the previously irradiated chips and the virgin chips is quite dramatic when looking at the relative rate of latch-ups and upsets. Prior irradiation not only increases the rate of both upsets and latch-ups, but it also makes the more
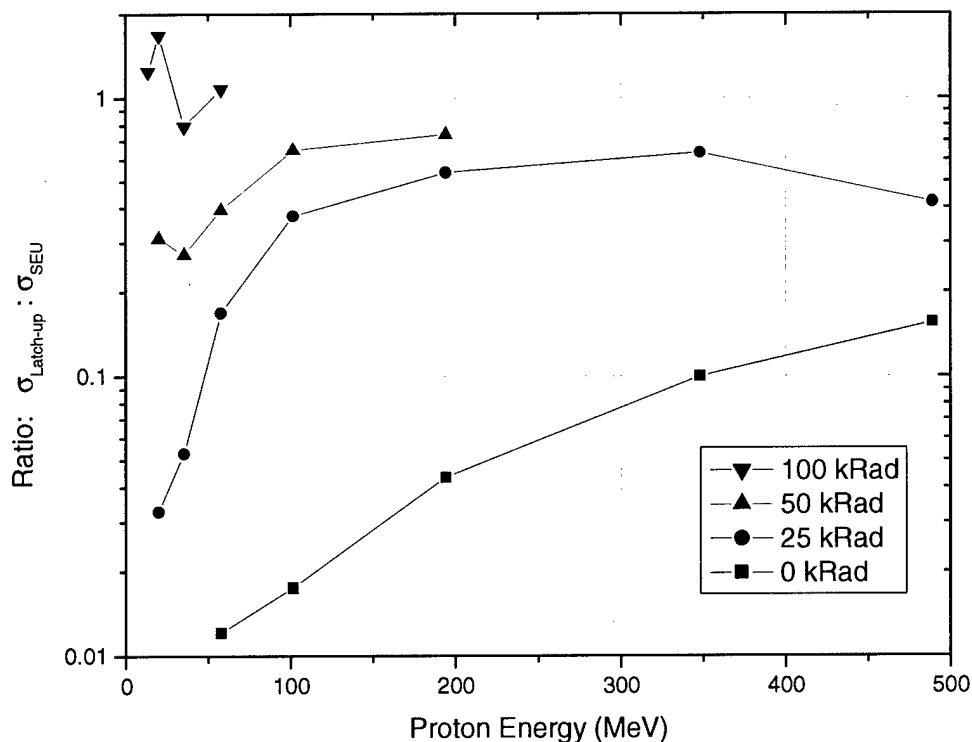
Figure 9. *The ratio between the measured latch-up and upset cross sections for the D431000ACZ-70L SRAM chips as a function of proton energy. There is a clear trend showing that the number of latch-up events (relative to SEU) increases with prior exposure to gamma radiation.*

destructive latch-up events more likely relative to the upset events. This could have dramatic effects on the operation of an SRAM chip in a space environment where both gamma and proton radiations are present. The virgin chips showed no signs of latch-up events at energies below 57.7 MeV. This onset of latch-up events at 57.7 MeV could have been caused by the dose that the chips absorbed from the proton irradiations, as this was on the level of 1 kRad(Si)/irradiation.

As discussed in section 4.1 the important effect for the operation of an SRAM chip in a space environment is the number of likely upsets for the duration of the mission. Figure 10 shows a plot of the number of expected upsets for the D431000ACZ-70L SRAM chip that was tested. The calculations of the number of upsets were done using a $1/E$ energy spectrum convolved with the fitted Bendel 2-parameter curves from Figure 4. The plots in Figure 10 are shown as a function of the cut-off energy for the integral (see section 2.2). The plots in Figure 10 are meant for comparison with each other, and not as a prediction of the number of upsets for a particular orbit. To make such a prediction, the details of the proton environment for a specific orbit would have to be used for the convolution.
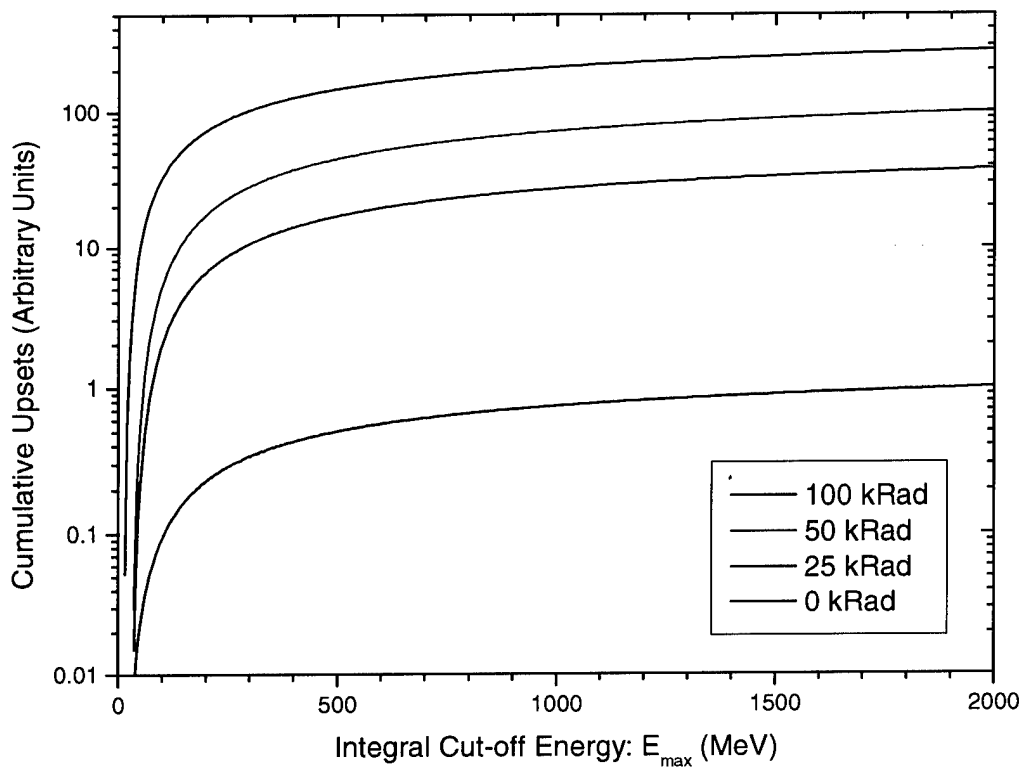
Figure 10. Cumulative upsets for the D431000ACZ-70L SRAM chips in a proton environment with energy spectrum as outlined in section 2.2. The cumulative upsets are shown, in arbitrary units, as a function of cut-off energy for the integral. The results have been normalized to make upsets for the virgin parts (0 kRad) to be 1 at 2 GeV to allow for easy comparison between groups.

For a more meaningful comparison, a plot of the ratio of the number of expected upsets as a function of the integral cut-off energy is shown in Figure 11. This plot clearly shows the increase in the number of expected upsets with prior irradiation. The effects shown here for the D431000ACZ-70L chips are much greater than what was seen in the MT5C2568 chips, as discussed in section 4.1. The MT5C2568 chips showed a 50 to 60 % increase in upsets at 50 kRad and a 70 to 80 % increase in upsets at 100 kRad, as compared to virgin parts. Here the D431000ACZ-70L show an increase the expected number of upsets over virgin parts of 35 to 40 *times* at 25 kRad, 90 to 100 *times* at 50 kRad and up to 300 *times* for the 100 kRad group. That is a 30,000 % increase in upsets for the parts irradiated to 100 kRad(Si) prior to proton irradiation. There is a clear and dramatic increase in both the proton-induced upset and latch-up rate for the D431000ACZ-70L chips with prior irradiation.
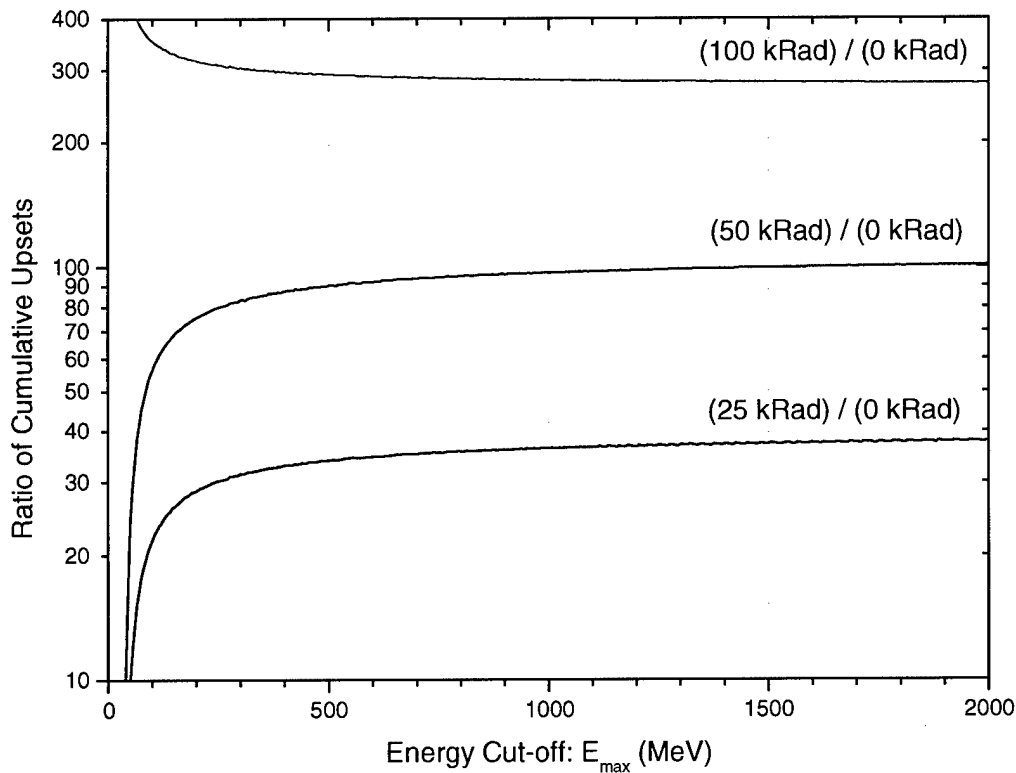
Figure 11. The ratio of cumulative upsets as a function of integral cut-off energy for the three different irradiation conditions of the D431000ACZ-70L SRAM chips. The chips irradiated to 25 kRad(Si) are expected to show 35 to 40 times more upsets than the virgin chips in a space (proton-rich) environment.. The chips irradiated to 50 kRad(Si) are expected to show 90 to 100 times more upsets than virgin chips and those irradiated to 100 kRad(Si) as much as 300 times more upsets than the virgin chips in a space environment.

5. Discussion

5.1 Hypothetical Mission Impact

In order to fully understand the impact of prior irradiation on the performance of SRAM parts it is useful to calculate the change in performance of one of the SRAM chips tested here due to the radiation environment of a real satellite over the duration of its mission. For this hypothetical case, the radiation environment of the Canadian satellite RADARSAT II will be used. The impact of a high altitude nuclear weapon blast will also be considered.

5.1.1 Radiation Environment of RADARSAT II

RADARSAT II is a Canadian radar-based imaging satellite set for launch in 2003. The radiation environment of RADARSAT II has been calculated and reported on by DREO [9]. The DREO calculations determined the energy spectrum of electrons, protons and heavy ions from trapped, cosmic ray and solar flare sources. Using these spectra, the absorbed dose in a variety of shielding configurations was calculated for the mission duration.

The total absorbed dose as a function of thickness of aluminum shielding is shown in Figure 13. These calculations are taken from Varga, Pepper and Woods [9] and assume an infinitely thick shield on one side, and finite thickness shield on the other side of the point where the dose is calculated. Calculations of the upset rate for the D431000ACZ-70L chips will be done for two shield thickness: 0.254 cm and 0.508 cm. These thicknesses of shielding were chosen to correspond to those considered by Lucero, Sulham and Hilland [10] for nuclear weapon environments.

The proton energy spectrum due to trapped, solar flare and cosmic ray protons, as calculated by Varga et al. [9] is shown in Figure 13. This spectrum assumes that there is no shielding on one side of the device and infinite shielding on the other. Also shown in Figure 13 are the modified proton spectra for the shielding configurations with 0.254 cm and 0.508 cm aluminum shielding. The effect of shielding on the proton spectrum is to eliminate the lowest energy protons and reduce the energy of those that are able to penetrate the shielding. The shielding has little effect on the high-energy portion of the spectrum, but significantly changes the low-energy portion. The changes in the proton spectrum due to the shielding were calculated using the program "Stopping and Range of Ions in Matter" or SRIM-2000 [11].
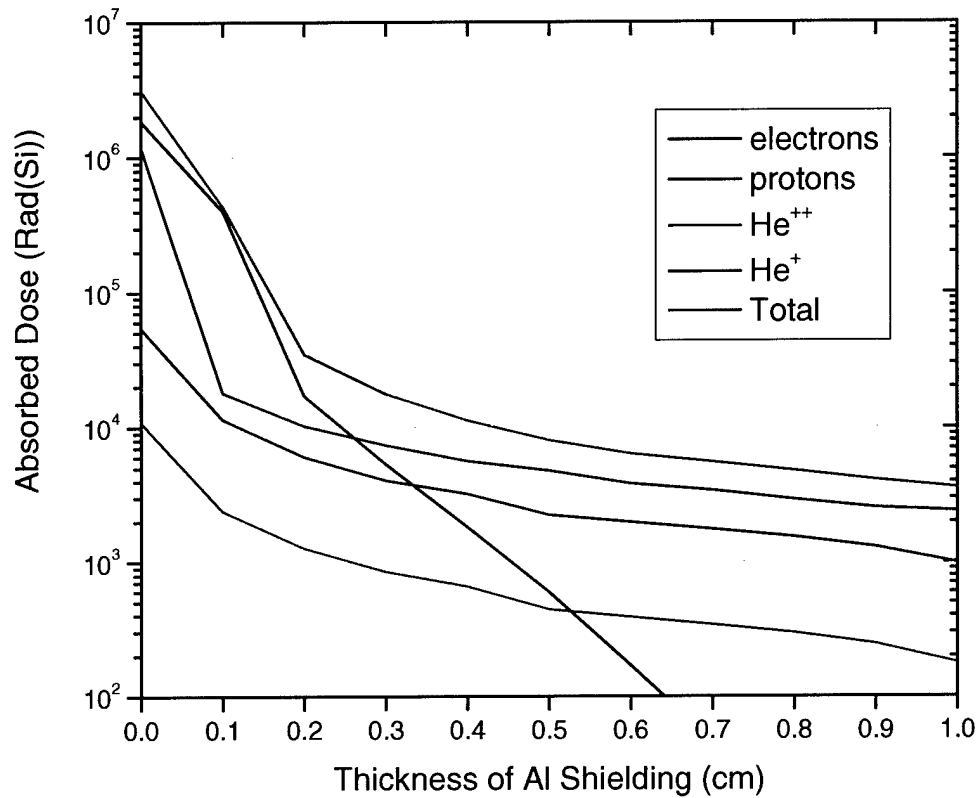
Figure 12. The total mission (5.25 years) absorbed dose as a function of aluminum shielding thickness for RADARSAT II [9]. Shown is the dose contribution from electrons, protons and both partially and fully ionized helium. The calculations assume an infinitely thick shield on one side of the device and an aluminum shield of thickness shown on the other side.
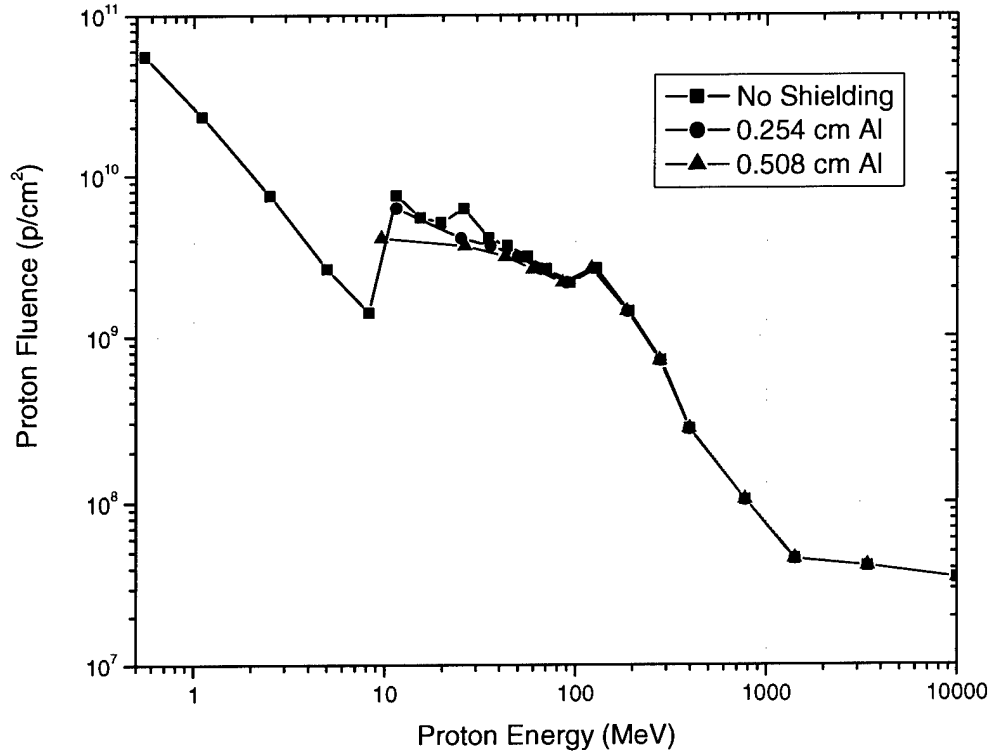
Figure 13. *The proton energy spectrum for three different shielding configurations for RADARSAT II. Shielding has the effect of eliminating the lowest energy protons, and reducing the energy of the protons that are energetic enough to penetrate the shielding. The high-energy portion of the spectrum remains relatively unaffected by the shielding. To generate these spectra the calculated spectrum from Varga et al. [9] was modified using calculations from SRIM 2000.*

5.1.2 Exo Nuclear Weapon Environment

Lucero, Sulham and Hilland [10] have calculated the radiation environment for satellites for a variety of scenarios involving exo-atmospheric nuclear detonations. Their calculations include the total dose delivered to a satellite with 0.254 cm and 0.508 cm aluminum shielding following 50 kT and 1 MT nuclear detonations at various distances from the satellite. The detonation is considered to be at 500 km altitude, but at three different latitudes. The effects on satellites were considered for an altitude of 1000 km as well as for GEO and half-GEO orbits. RADARSAT II will be at an average altitude of 800 km, so only the 1000 km burst effects will be considered. The doses quoted are those delivered to the satellite in 21 days following detonation. The range of delivered dose for the various scenarios considered is summarized in Table 5.

Table 5. *Range of doses delivered to a satellite following an exo-atmospheric nuclear weapon detonation. These data are a summary of the calculations done by Lucero, Sulham and Hilland [10, calculation details can be found in their paper. These doses correspond to those delivered to a satellite at 1000 km altitude over 21 days following a detonation at 500 km altitude.*

Shielding (cm Al)	Burst Yield (kT)	Dose (Rad(Si))	
		Min	Max
0.254	50	4.50×10^2	5.40×10^4
	1000	9.65×10^3	1.13×10^6
0.508	50	9.39×10^1	1.09×10^4
	1000	2.02×10^3	2.28×10^5

In the three weeks following a 50 kT nuclear detonation at 500 km altitude, satellite components could be exposed to approximately 50 kRad(Si) for 0.254 cm Al shielding or 10 kRad(Si) for 0.508 cm Al shielding.. For a 1 MT detonation the dose can be as high as 1.1 MRad(Si) for 0.254 cm Al shielding or 230 kRad(Si) for 0.508 cm Al shielding. For RADARSAT II, these estimates are likely low, due to the fact that its average altitude is approximately 800 km, and is likely to be much closer to a 500 km high detonation. Nevertheless, 50 kRad(Si) and 10 kRad(Si) (for the two shielding configurations) can be used as reasonable estimates of the dose delivered to satellite components following a 50 kT exo-atmospheric nuclear detonation. For a larger nuclear detonation, on the order of 1 MT, these estimates are quite conservative.

5.1.3   Impact on D431000ACZ-70L SRAM Chips

The impact of natural and NWE radiation exposure on the operation of D431000ACZ-70L SRAM chips can be estimated by convolving the known proton spectrum for RADARSAT II (section 5.1.1) with the measured upset cross section for these devices (section 4.2). The upset cross section has been measured for parts irradiated with 0, 25, 50 and 100 kRad(Si) of gamma radiation prior to proton exposure. The number of latch-up events can also be estimated by using the ratio between the latch-up cross section and the upset cross section, as shown in Figure 9. The rates of upsets and latch-ups can be estimated for the four different irradiation conditions and for the two different shielding configurations studied. These results are summarized in Table 6.

Table 6. *Upset and Latch-up rates for the D431000ACZ-70L SRAM chips in a RADARSAT II radiation environment for three different shielding configurations and for four different TID exposures. All rates are given in events/day. The latch-up rates for 50 and 100 kRad(Si) for high energy protons are estimated to be 80% and 100 % of the upset rate respectively (based on results in Figure 9).*

Shielding (cm Al)	0 kRad(Si)		25 kRad(Si)		50 kRad(Si)		100 kRad(Si)	
	Upset	Latch	Upset	Latch	Upset	Latch	Upset	Latch
0	4.45	0.0150	125	52.3	328	262	1450	1450
0.254	3.90	0.0145	114	49.1	301	241	1230	1230
0.508	3.52	0.0141	106	46.4	280	224	1090	1090

From the results quoted in Table 6, it is obvious that the amount of ionizing radiation that the D431000ACZ-70L SRAM chips are exposed to has a great effect on the rate of both upsets and latch-ups. In considering the case with 0.254 cm thick aluminum shielding, the effect of natural radiation and that from a nuclear weapon can be easily seen.

For a virgin part with a 0.254 cm aluminum shield in the RADARSAT II orbit, the expected rate of upsets is 3.9/day for a total of 7490 over the course of the 5.24 yr mission. The latch up rate is expected to be 0.0145/day for a total of 279 over the course of the mission. The natural radiation environment of RADARSAT II means that the chip will be exposed to approximately 25 kRad(Si) over the course of the mission, making the rate of upsets approximately 114/day and the rate of latch-ups approximately 49/day near the end of the mission. This is a 30 times increase in upset rate and a 3400 times increase in the latch-up rate for this part.

If the part were to be exposed to a 50 kT nuclear weapon detonation during its mission it could be exposed to 50 kRad(Si) TID. This would cause a dramatic increase in the upset and latch-up rates for this device. A 50 kRad(Si) exposure would cause an upset rate of 301/day and a latch-up rate of 241/day, an increase of 77 times in upset rate and 16,600 times in latch-up rate over virgin parts.

5.2 Future Plans

The results of this investigation show quite conclusively that there is a very significant enhancement in both the upset and latch-up cross sections for the SRAM devices that were tested. The existence of this stress-synergy phenomenon opens up a whole realm of possibilities for further study.

A variety of other SRAM devices should be tested in a similar manner in order to determine whether or not other SRAM devices show these effects and, if so, to what extent. A comparison of the stress-synergy effect between different SRAM architectures could point to the physical basis of this phenomenon.

Other studies should be done to look for the effect of dose rate on the strength of this stress-synergy phenomenon. The phenomenon of Enhanced Low Dose Rate Sensitivity (ELDRS) is a well-known enhancement in the damage caused by radiation and may also lead to an enhancement in the stress-synergy effect. DREO is planning a study that will address this possibility.

DREO is also involved in the investigation of a possible stress-synergy effect in analog devices. These experiments will look at the performance of comparators and op-amps in a variety radiation fields after exposure to different doses of gamma radiation.

6. Conclusions

Two different types of SRAM devices were tested to determine their susceptibility to proton-induced single event effects, subsequent to exposure to various total ionizing doses (TID) of gamma radiation. These experiments were designed to determine the effect that TID has on the cross section for single event effects. Gamma irradiations were performed at Defence Research Establishment Ottawa (DERO) and the proton irradiations were performed at the Proton Irradiation Facility at the Tri-University Meson Facility (TRIUMF PIF) on UBC campus in Vancouver, British Columbia.

The first devices tested were MT5C2568 SRAM chips. These devices showed an increase in the single event upset (SEU) cross section that would lead to a 50 % and 70 % increase in the number of expected upsets for chips exposed to TID of 50 kRad(Si) and 100 kRad(Si) respectively. The expected number of upsets was calculated for a proton-rich environment with a 1/E energy spectrum.

The second set of chips that tested was comprised of D431000ACZ-70L SRAM. These devices showed a large increase in the SEU cross section with TID, and they also exhibited a large number of latch-up events. The impact of the increase in the SEE cross sections was calculated for a 1/E proton environment as well as for the radiation environment of RADARSAT II. The increase in the expected number of upsets in a 1/E proton environment was determined to be approximately 30, 100 and 300 times greater for parts exposed to 25, 50 and 100 kRad(Si) TID respectively than for virgin parts.

For D431000ACZ-70L SRAM chips in the radiation environment of RADARSAT II, the expected number of upsets per day is 3.9, 114, 301 and 1230 for chips exposed to 0, 25, 50 and 100 kRad(Si) TID respectively. The increase in the number of latch-up events is even more dramatic. For D431000ACZ-70L SRAM chips in the radiation environment of RADARSAT II, the expected number of latch-up events per day is 0.0145, 49.1, 241 and 1230 for chips exposed to 0, 25, 50 and 100 kRad(Si) TID respectively. All of these estimates are for 0.254 cm aluminum shielding. Chips in the RADARSAT II orbit with these shielding parameters are exposed to 25 kRad(Si) TID over the course of their 5.25 year mission, and could easily be exposed to 50 kRad(Si) in the event of an exo-atmospheric nuclear detonation. The increase in the upset rate, and the large number of latch-up events after these TID exposures would greatly deteriorate the performance of the D431000ACZ-70L SRAM chips.

This study has addressed the major concerns of the NATO NPSG committee [2] in regards to synergistic effects in electronics exposed to mixed radiation fields. It has confirmed that a synergistic effect exists for the damage produced by different components of a mixed radiation field. In light of these findings, there should be a re-evaluation of the fundamental assumptions and current practices in qualifying components for space applications.

7. References

1. Leray, J-L., "Stress-Synergy: Combined Radiation Effects on Satellites". Presented at NATO NPSEG ARP-50 meeting, Ottawa, Ontario, September 1999.

2. Minutes: "NATO Nuclear Protection Sub-group Meeting", January 2000.

3. Cousins, T. and O'Kuma, J., "DREO/WSMR Stress Synergy Work". NATO NPSG Meeting, March 2001.

4. Messenger, G.C. and Ash, M.S., "The Efects of Radiation on Electronic Systems" Van Norstrand and Reinhold Company Inc., New York (1986).

5. Holmes-Siedle, A. and Adams, L., "Handbook of Radiation Effects" Oxford University Press (1993).

6. Bendel, W.L. and Petersen, E.L., "Proton Upsets in Orbit", IEEE Transactions on Nuclear Science, NS-30, 4481 (1983).

7. Stapor, W.J., Meyers, J.P., Langworthy, J.B. and Petersen, E.L., "Two Parameter Model Calculations for Predicting Proton Induced Upsets", IEEE Transactions on Nuclear Science, NS-37, 1966 (1990).

8. Shimano, Y. et al., "The Measurement and Prediction of Proton Upsets ", IEEE Transactions on Nuclear Science, NS-36, 2344 (1989).

9. Varga, L., Pepper, G.T. and Woods, P., "Space Radiation Environment Estimation for RADARSAT II" DREO Report 1292, July 1996.

10. Lucero, S.L., Sulham, Lt. C.V. and Hilland, D.H., "Exo Nuclear Weapon Environments for Satellites" Chapter 2, AEP-50 "Guidelines for Radiation Hardening of Satellite Electronics and Photonics"

11. Ziegler, J.F., Biersack, J.P. and Littmark, U., "The Stopping and Range of Ions in Solids" Pergammon Press (1999).

Appendix A: Address to Bit Error Correction

A software problem with the JD Instruments ATV Digital Tester made it necessary to estimate the number of bit errors that occurred during the irradiation of certain SRAM chips, given only the number of memory addresses that reported errors. Each memory address is a grouping of 8 bits. When errors occur in two or more bits within a single address location, this is reported as a single address error.

When the number of address errors is small compared to the total number of addresses in the SRAM chip, the bit-error count and the address-error count closely match each other. The greater the numbers of errors, the more these two counts diverge. Assuming that the errors occur randomly, with the same probability for each individual bit, an expression for the probable number of bit errors, given a number of address errors can be derived as follows:

The variables that will be used for this are listed in Table 7.

Table 7. *Variables used in the derivation of the expression for the estimate of the number of SRAM bit errors given a specific number of address errors.*

Variable	Description
p	Probability of an error occurring for a bit
$q = 1\text{-}p$	Probability that no error occurs for a bit
P	Probability of an error occurring in an address
$Q = 1\text{-}P$	Probability that no error occurs in an address
n	Number of bits in an address
N_a	Number of addresses in the SRAM
$N_b = n\,N_a$	Number of bits in the SRAM
E_b	Number of bit errors
E_a	Number of address errors

If one takes the probability of an error occurring in a specific bit during an irradiation to be p, then the probability that the bit survives the irradiation, q, is given by:

$$q = 1 - p$$

The probability that all n bits in an address survive the irradiation is then given by:

$$Q = q^n$$

The probability, p, of an error occurring in a specific bit can then be written as:

$$p = 1 - \sqrt[n]{Q}$$

The probability of an address surviving the irradiation can be expressed in terms of known or measured quantities:

$$Q = \frac{N_a - E_a}{N_a}$$

The probable number of bit errors can then be expressed as a function of the measured number of address errors and the details of the SRAM under study:

$$E_b = pN_b = N_b \left(1 - \sqrt[n]{\frac{N_a - E_a}{N_a}} \right)$$

This expression diverges as the number of address errors approaches the total number of addresses in the SRAM. The uncertainty in this correction increases with the number of address errors. In the case of the D431000ACZ-70L SRAM chips, the number of addresses is $N_a = 2^{17} = 131072$. Data for these chips were no longer taken after the number of address errors reached approximately 110000. At this level there are approximately 5 bit errors for every address error and the uncertainty in the number of bit errors is approximately 2.5 times that in the number of address errors. The uncertainty in the bit error number increases dramatically after this point.

The authors would like to thank S. Drake and J. Laforce for their help in deriving this correction.

Appendix B: Bendel Fit Parameters

The parameters for the Bendel 2-parameter fits shown in Figure 4 and Figure 7 are tabulated here. The equation for the fitting function is given in section 2.1. The parameters for the MT5C2568 SRAM chips (Figure 4) are shown in Table 8, and the parameters for the D431000ACZ-70L SRAM chips (Figure 7) are shown in Table 9. All of the curves were fit using ORIGIN 6.1 with a custom fitting function.

Table 8. Bendel 2-parameter fit parameters for the MT5C2568 SRAM chip SEU data. These parameters are for the fitted curves shown in Figure 4.

Group	Prior Dose kRad(Si)	A (MeV)	S ($\times 10^{-12}$ cm^2/bit)
M1	0	8.26	0.338
M2	50	4.72	0.463
M3	100	4.95	0.520

Table 9. Bendel 2-parameter fit parameters for the D431000ACZ-70L SRAM chip SEU data. These parameters are for the fitted curves shown in Figure 7.

Group	Prior Dose kRad(Si)	A (MeV)	S ($\times 10^{-12}$ cm^2/bit)
D1	0	18.6	0.128
D2	25	30.4	5.40
D3	50	31.1	14.5
D4	100	13.6	33.2

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence Research Establishment Ottawa 3701 Carling Avenue Ottawa, Ontario K1A 0Z4	2. SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable) UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)

Stress Synergy in Proton Induced Single Event Effects in SRAM (U)

4. AUTHORS (Last name, first name, middle initial)

Erhardt, Lorne S.; Cousins, Tom and Estan, Diego

5. DATE OF PUBLICATION (month and year of publication of document) November 2001	6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.) 37	6b. NO. OF REFS (total cited in document) 11

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Report

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

Space Systems & Technology Section
Defence Research Establishment Ottawa
Ottawa, Ontario K1A 0Z4

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant) 5ep11	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) DREO TR 2001-122	10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

Unlimited Announcement

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

A study was conducted to determine the effect of prior exposure to radiation on the proton-induced single event effect (SEE) cross section for SRAM devices. This was done in order to determine whether or not proton testing of virgin parts accurately determines the likely rate of single event effects for these parts in a space environment. Two types of SRAM parts were exposed to various doses of gamma radiation and then tested with identical proton irradiations to determine their SEE cross sections. The results of these experiments were analyzed to determine the expected number of SEE events for these devices in typical space radiation environments, including the radiation environment of RADARSAT II. Both types of SRAM chips showed an increase in the SEE rate with prior radiation exposure. One type of SRAM, the D431000ACZ-70L, showed such a dramatic increase in the SEE rate that early failure in a satellite mission due to natural radiation, or in the event of an exo-atmospheric nuclear detonation, is likely.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

SEE, SEU, single event effects, single event upset, latchup, SRAM, proton, irradiation, stress synergy